# Energy Overhead of Meltdown and Spectre Mitigations on Linux

GI Fachgruppe Betriebssysteme – Herbsttreffen
September 22, 2021

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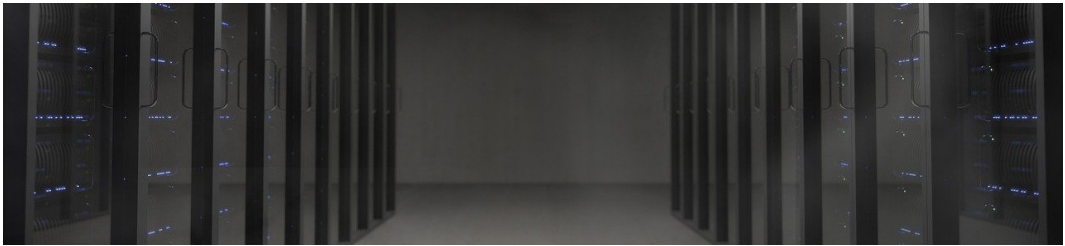
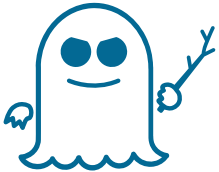
# The Price of Meltdown and Spectre





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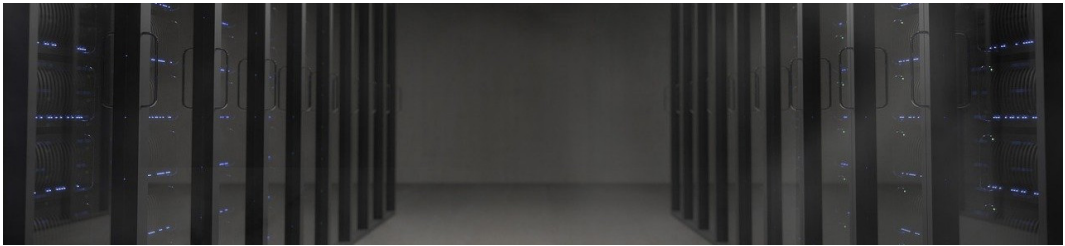
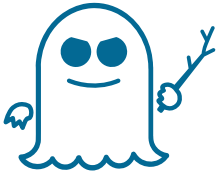




# The Price of Meltdown and Spectre (2)

**The goal of this work is to put a price tag on the Meltdown/Spectre software mitigations in terms of their energy overhead[1].**

[1] Herzog et al., **The Price of Meltdown and Spectre: Energy Overhead of Mitigations at Operating System Level**. *Proc. of the 14th European Workshop on Systems Security (EuroSec'21). 2021*

# Research Questions

**Q1** **How much energy overhead** is introduced by Meltdown/Spectre mitigations?

**Q2** Is the energy overhead **related to specific subsystems** (e.g., CPU, block I/O)?

**Q3** Is the energy overhead **correlated with the execution time** overhead?

**Q4** Is the energy overhead **predictable** for a given application?

# Agenda

Motivation

Meltdown and Spectre Mitigations

Energy Overhead Analysis

Energy Overhead Prediction

Conclusion

# Meltdown and Spectre Attacks and Mitigations

## Attacks

- class of hardware vulnerabilities
- (time) side-channel based
- bypass memory access protection

## Mitigations

- full mitigation at hardware-level
- partial mitigation at software-/firmware-level

# Meltdown and Spectre Attacks and Mitigations (2)

**Attacks**

**Mitigations**

**Meltdown:**

→ Linux `[no]pti`

Kernel Page Table Isolation (KPTI)

**Spectre v1:**

→ Linux `[no]spectre_v1`

`swapgs`/usercopy barriers,
pointer sanitization

**Spectre v2:**

→ Linux `[no]spectre_v2`

retpolines,
Indirect Branch Restricted Speculation (IBRS),
Return Stack Buffer (RSB) refilling

# Measurement Methodology

**Benchmarks**

Training/Analysis — Evaluation

| sysbench | stress-ng | Phoronix |
|---|---|---|
| 4 benchmarks | 24 benchmarks | 10 benchmarks |
| 20 s-300 s exec. time | 20 s-300 s exec. time | 2 m-15 m exec. time |
| 10 (50) iterations | 10 (50) iterations | 10 iterations |

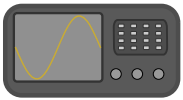
intermingle →

```
$> ./sysbench-1
$> ./stress-ng-1
$> ./sysbench-2
[...]
```

execute ↓

- Intel Core i5 8400 (2.8 GHz)
- 8 GB RAM
- 2 TB HDD
- 1 Gbit Ethernet
- Ubuntu 18.04 LTS
  - `nopti`
  - `nospectre_v1`
  - `nospectre_v2`

`perf` + **Intel RAPL**

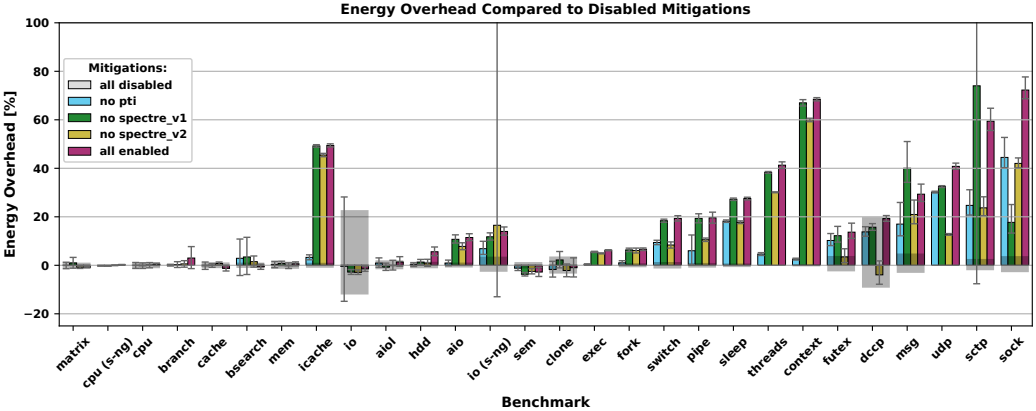


measure energy

collect performance counters →

- 4 perf. counters
- one iteration
- 1 ms sampling rate
- CPU package

# Q1: Energy Overhead of Spectre/Meltdown



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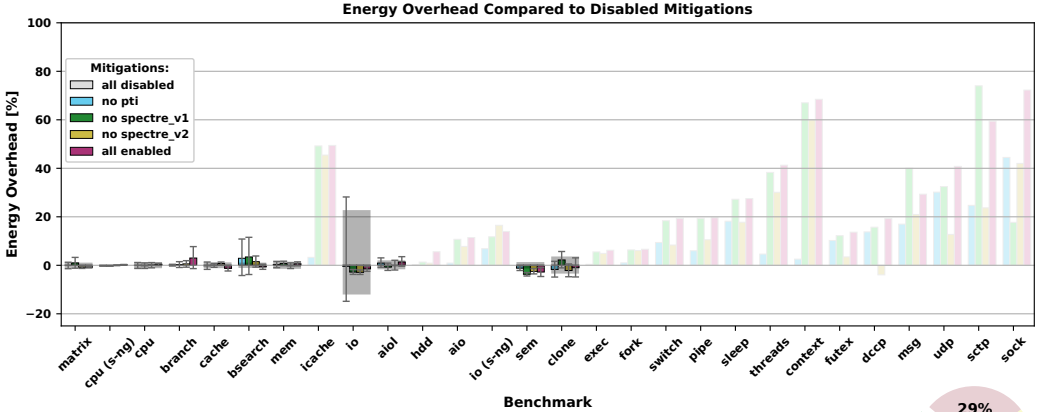
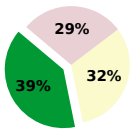



→ **11 out of 28 benchmarks have an overhead below 5 %**



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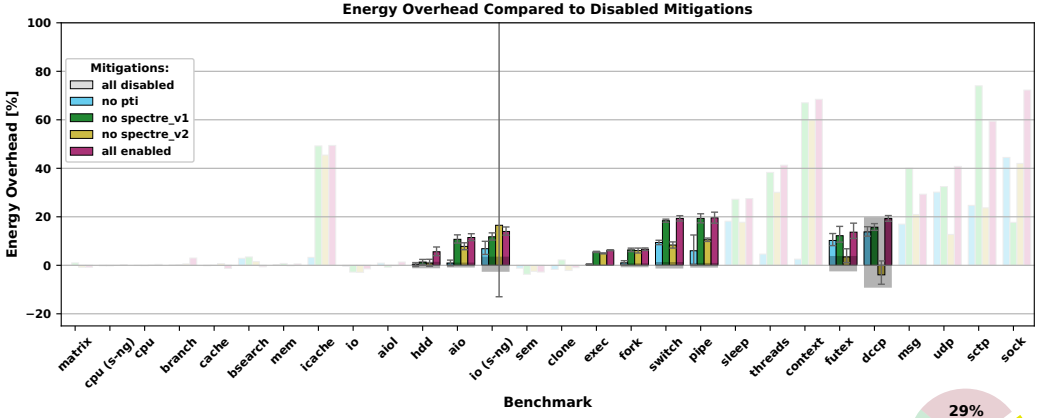
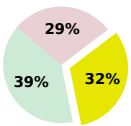



→ **9 out of 28 benchmarks have an overhead between 5 % and 25 %**



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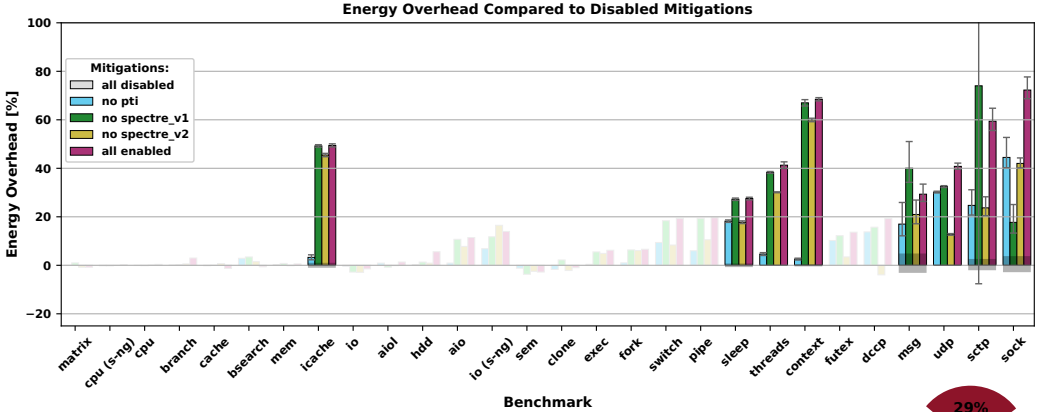
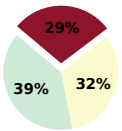



→ **8 out of 28 benchmarks have an overhead above 25 %**



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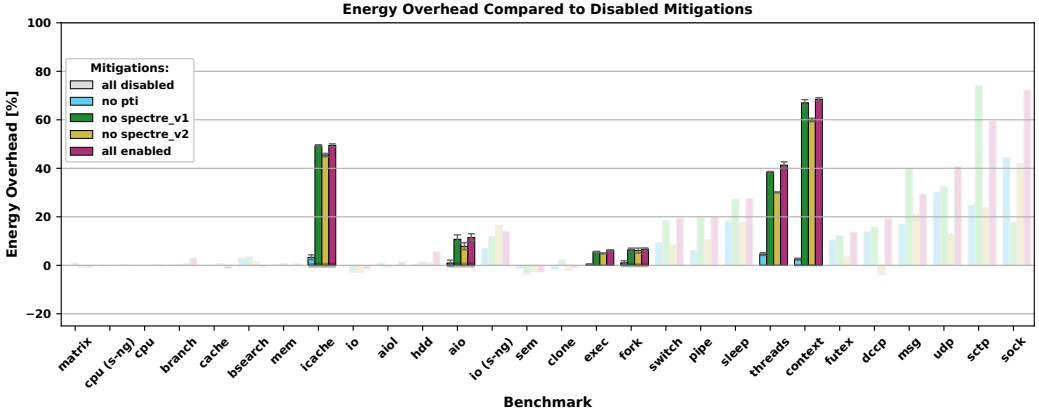


→ **KPTI often has the greatest influence**

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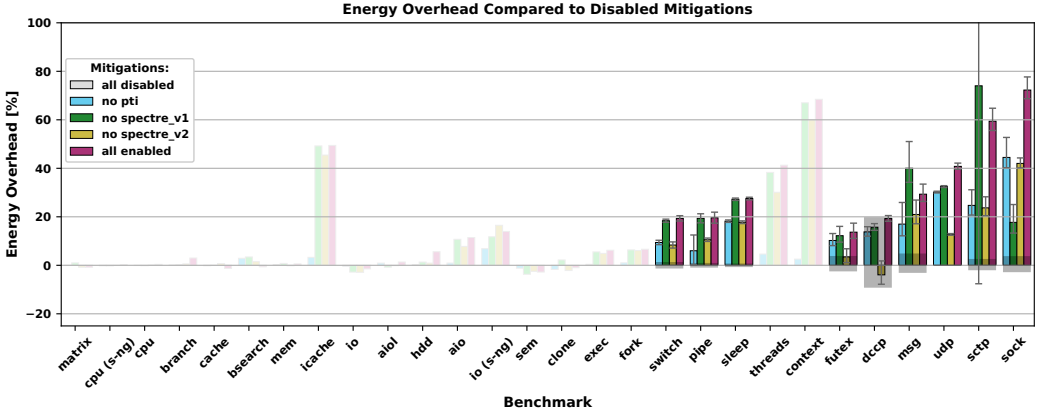


→ **Spectre v2 also contributes to the overhead**

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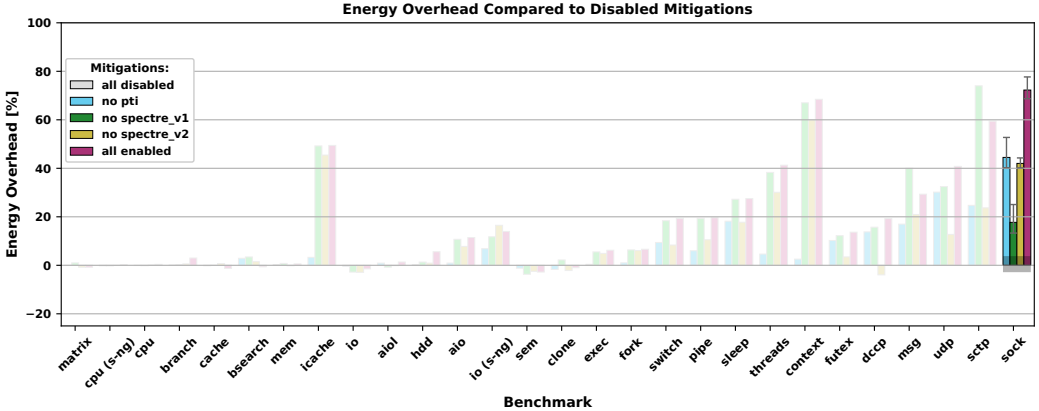
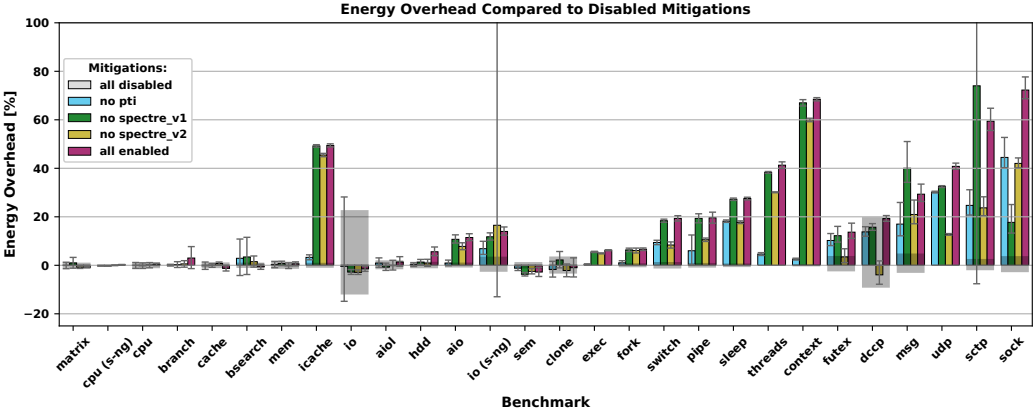


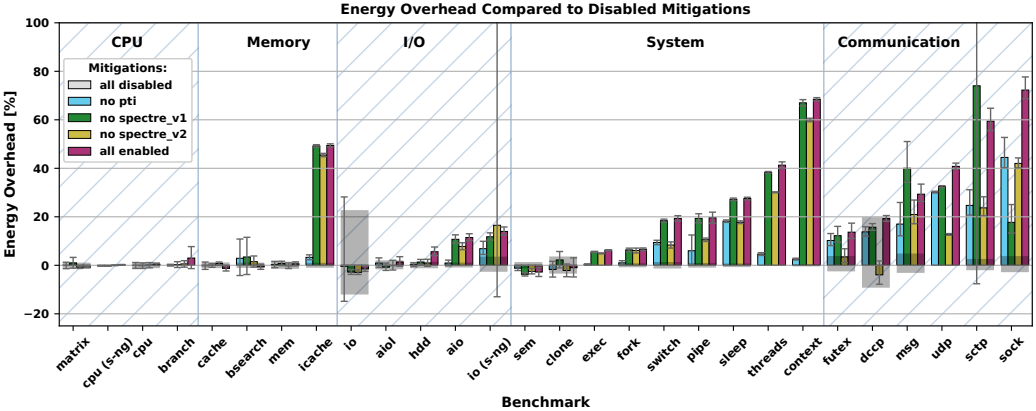

→ **Spectre v1 only influences one benchmark**

# Q1: Energy Overhead of Spectre/Meltdown




**The overhead is highly application-dependent and lies between ~0 % and 72 %.**

# Q2: Relations between Mitigations' Overhead and Subsystem



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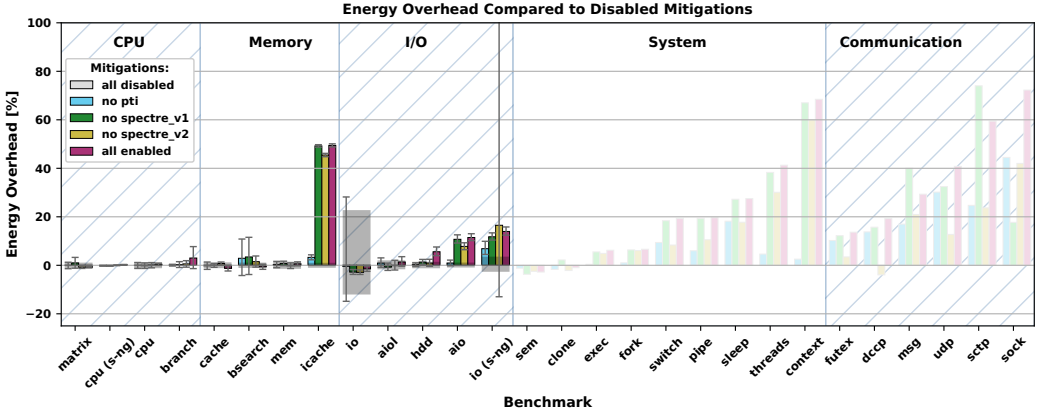


→ **CPU-, memory-, and I/O-heavy benchmarks have (mostly) no or small overheads**

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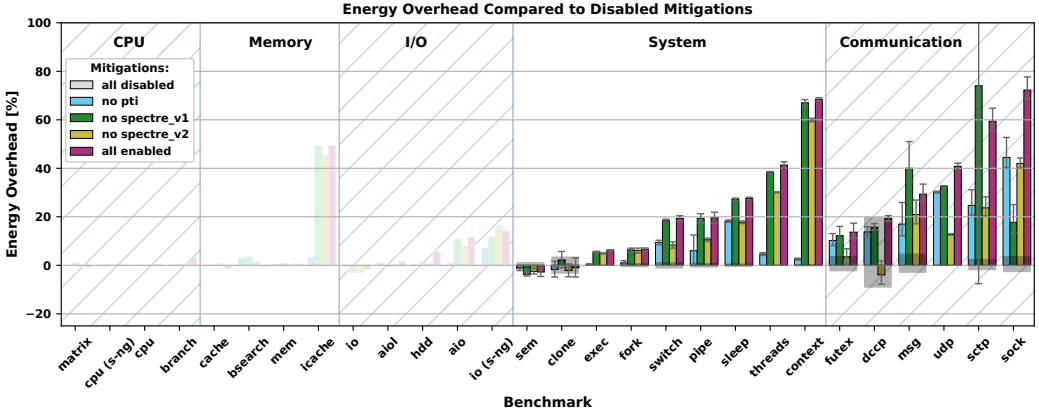


→ System- and communication-heavy benchmarks have in general higher overheads

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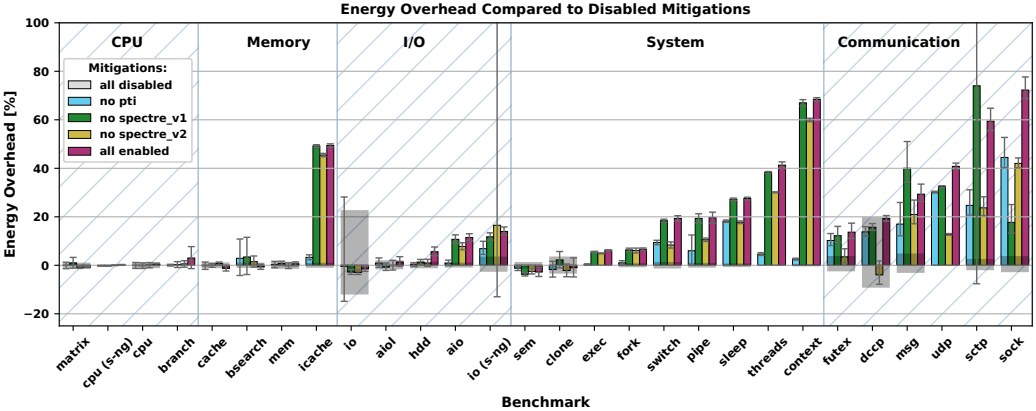
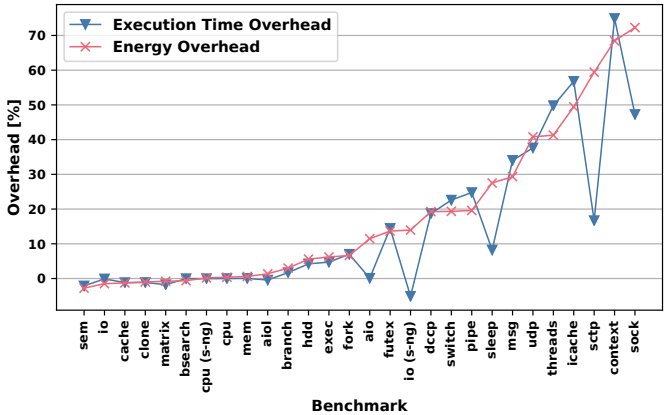



**System interactivity greatly influences the mitigations' overhead**

# Q3: Correlation between Energy and Execution Time Overhead




- positive correlation
- Spearman correlation coefficient: 0.88
- 5 noticeable exceptions

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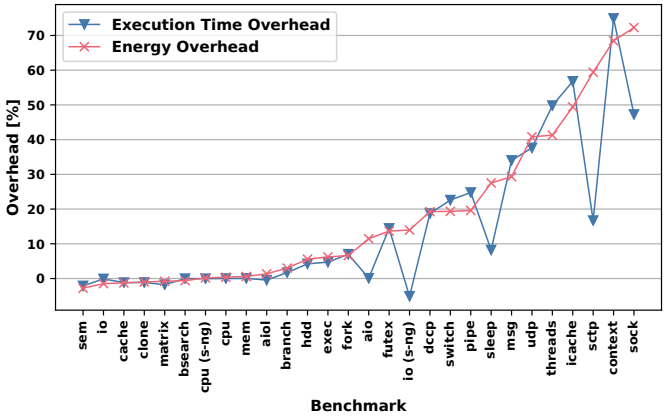


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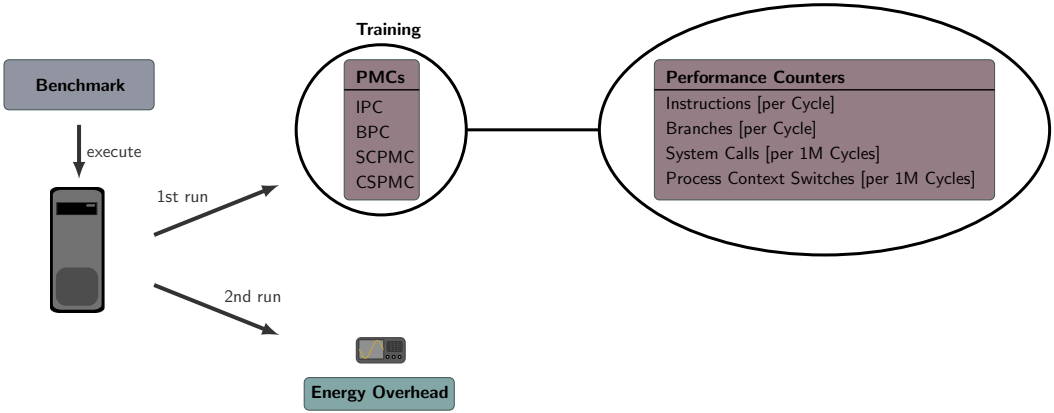
**Energy and execution time overhead are correlated (exceptions apply)**

# Energy Prediction Model



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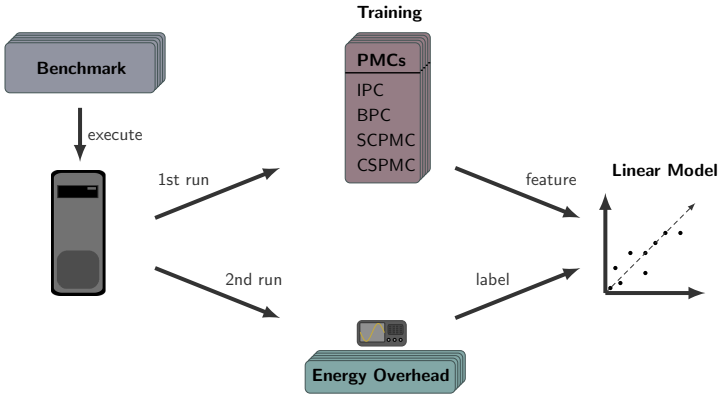

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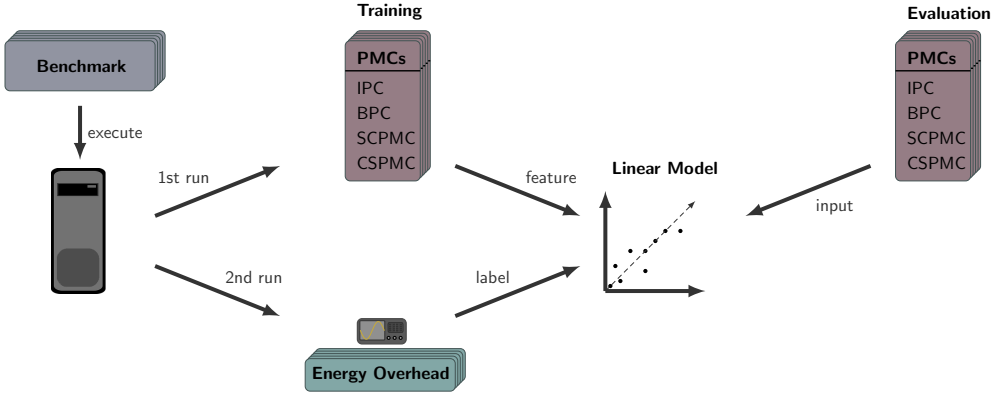

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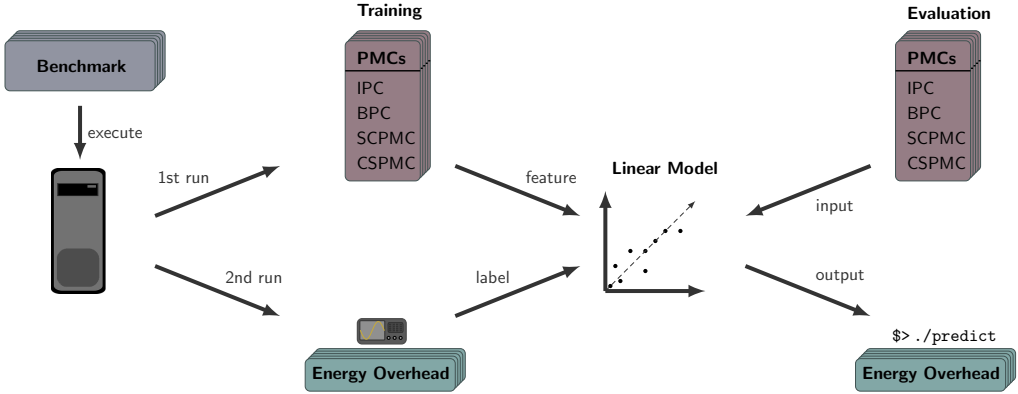

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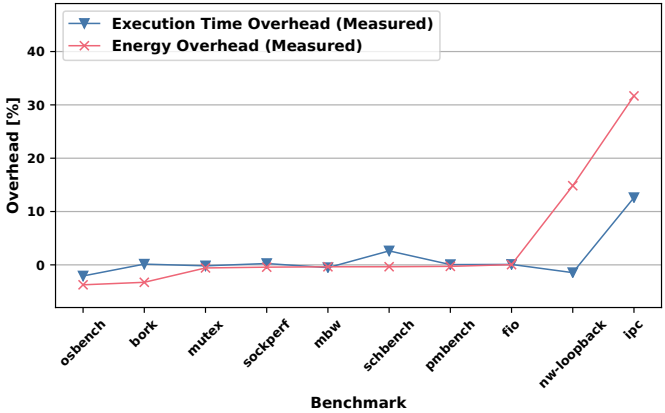


- 10 Phoronix benchmarks
- mostly no overhead
- `nw-loopback`: energy but no time overhead
- `ipc`: energy and time overhead

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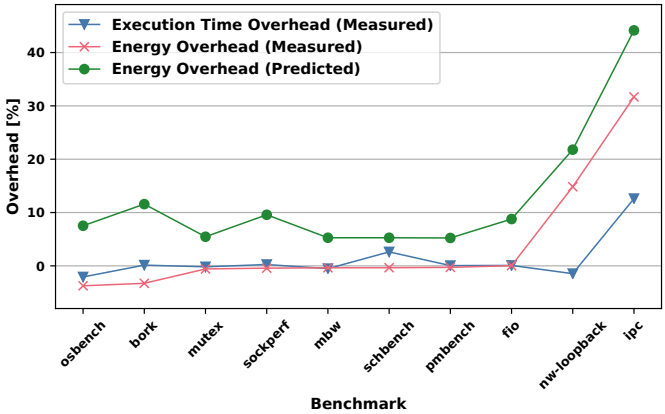


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- identifies benchmarks with energy overhead

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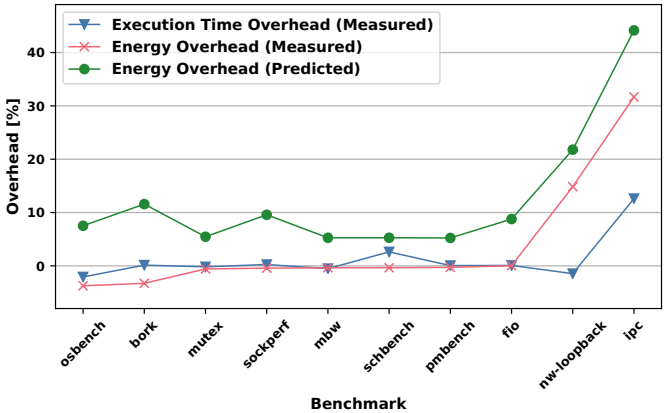


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**Linear model can identify applications with induced energy overheads**

# Performance Counter Correlation

| Performance Counters | Energy Overhead | Time Overhead |
|---|---|---|
| Instructions [per Cycle] | -0.06 | -0.02 |
| Branches [per Cycle] | -0.02 | -0.03 |
| System Calls [per 1M Cycles] | **0.64** | **0.64** |
| Process Context Switches [per 1M Cycles] | **0.41** | **0.33** |

**Spearman Correlation Coefficient**

| | |
|---|---|
| no correlation: | 0.00 |
| **strong correlation:** | **±1.00** |

# Conclusion

**Q1 Energy Overhead?**

→ application dependent (~0 % – 72 %)

→ especially mitigations against Meltdown and Spectre v2

**Q2 Subsystem Related?**

→ operating system interactivity increases overhead

**Q3 Execution Time correlated?**

→ exec. time and energy overhead correlated; exceptions apply

**Q4 Predictable?**

→ applications with overheads predictable

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